Can Electricity Save Energy?

by Hans De Keulenaer, email Hans.Dekeulenaer@sealnet.org
Joachim Grawe, email joachim.grawe@energie-fakten.de

May 2006

1 Introduction

While OECD countries increasingly decouple primary energy consumption from GDP growth, consumption of electricity as a major energy carrier continues to grow, in some cases even fast. For the coming decades, forecasts converge on a growth rate of 2.3-2.4% up to 2030, resulting in a demand of 31 524 TWh compared to 15 391 TWh today, i.e a doubling of demand [IEA02].

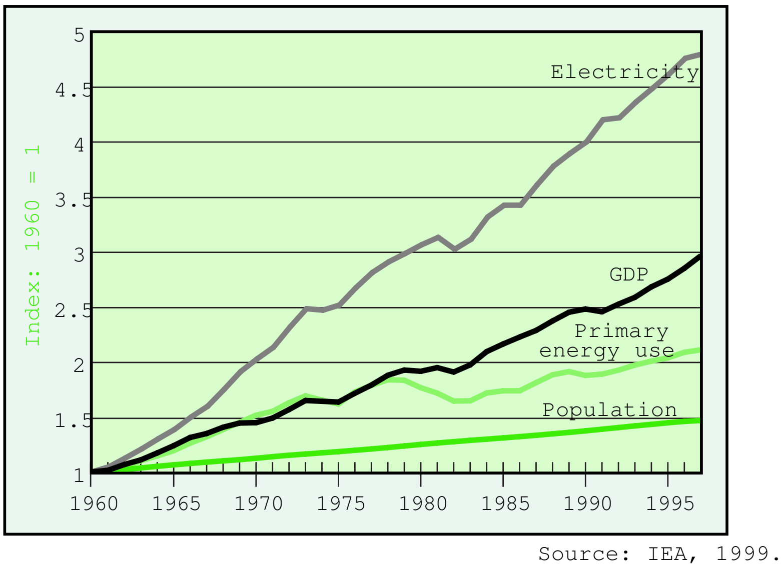

Figure 1: Trend in electricity use, energy use, population and GDP[WEA, 2000]

Growth in electricity consumption can be seen as fueling GDP growth. The independent Electric Power Research Institute in Palo Alto, California (EPRI) has formulated the view that modernising the US electricity infrastructure could increase economic productivity by 0.7% per year, resulting in an additional US$ 3 000 billion annual GDP by 2025 [EPRI, 2003].

As a result of this high growth, electricity's share in the total final energy mix has been steadily increasing. It is currently around 18% of final energy, and close to 40% of primary energy consumption. In the light of this growth, views of an 'all electrical' society have been occasionally expressed.

The high growth of electricity can also be seen as a problem. Is electricity the 'bad student', hindering primary energy demand to go down in absolute terms? Is electricity a high quality but polluting energy form, that should be only used when there is no alternative?

But electricity is just an energy carrier, which due to its high quality, can be converted with high efficiency into practically any energy service. Referring to table 1, an integrated resource viewpoint should be taken when evaluating the efficiency of electricity to deliver energy services. For example, table 1 shows that an electric vehicle can be about twice as efficient in converting primary energy into transport services.

ICEV	η	EV	η
Oil refinery	85-90%	Gas transport	95%
Distribution	95-99%	Generation	55%
Engine	15-20%	T&D	90-96%
Transmission	95-98%	Battery	60-70%
		Motor	80-85%
		Transmission	95-98%
Well-to-wheel	12-17%	Gas-to-wheel	21-29%

Table 1: Comparing system efficiency for Internal Combustion Engine (ICEV) and Electric Vehicles (EV) (based on [Husain])

Based on the integrated resource view, we can speculate that it is actually the growth in electricity consumption that is pushing down primary energy demand below GDP growth, a view which is today as speculative as its alternative mentioned above.

2 Characteristics of electricity

Electricity is a product, and just like any other product, it has certain quality characteristics such as voltage level and tolerance, frequency, environmental performance, ... But it also has very unique features.

The main characteristic of electricity is its high quality, and its resulting capability to serve practically any energy service (light, appliances, motion, electronics, heat) from a single system. The price to pay for this high quality is the conversion loss in the thermal power station, a loss that has been steadily decreasing over the past century, and is now approaching its thermodynamical limit (fig 2). Serving all energy needs from a single system reduces cost of technical installations to the end-user. The capital becoming available could be used to invest in energy conservation (insulation), energy efficiency (class A+ appliances) or renewable generation.

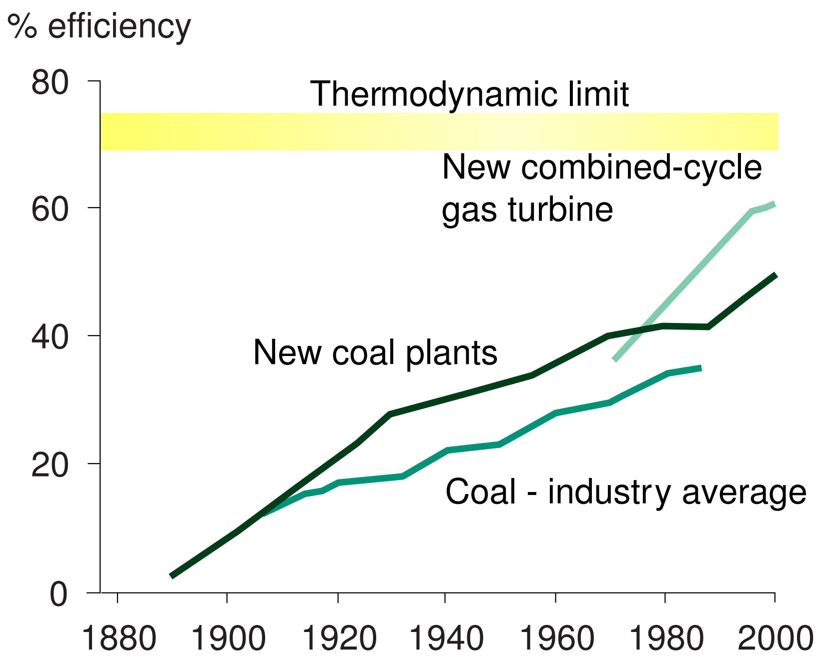

Figure 2: Efficiency improvement of power stations [WBCSD, 2000]

Electricity also has some disadvantages. It cannot be stored in large quantities in a practical way and at reasonable cost. As a result, supply and demand must match at all times in a fragile balance. It's the ultimate just-in-time product, consumed at the moment it is being produced, without the possibility for quality control. In fact, its users have as much influence over its quality than its suppliers [LPQI01].

Considering this fragile balance, it is all the more amazing that we observe in practice between 30 and a few 100 minutes of (unplanned) interruptions per year in the electricity system of the various OECD countries [CEER, 2005]. For example 100 minutes lost corresponds to 0.02% of the minutes in a year, or 99.98% availability. The best performance is achieved in the electricity systems of Austria, Germany and the Netherlands, and such high performance may not even be sufficient to power the digital economy. Meanwhile, the question remains whether the emerging electricity system of the future will be able to achieve the higher goal.

3 Conversion losses

When power stations convert primary energy into heat, and then into electricity, the conversion efficiency varies between 30% (older power stations) and 60% (modern gas-fired combined cycle stations). Therefore, the share of electricity in the energy mix differs dramatically between primary energy and secondary energy (or final energy).

In the final energy mix, electricity currently represents a share of 18% on average. When converting this amount back to primary energy, a method called the 'physical energy content' is often used [IEA]. For example:

- Renewables: a factor 1
- Nuclear: factor 3
- thermal power plants: factor $1/\eta$ (e.g. 2.5 or 1/40% for coal, 1.7 or 1/60% for gas)

The average 'physical energy content' of electricity for Europe is around 2.5, i.e 2.5 kWh of primary energy is needed for each kWh of electricity. For a (hypothetical) electricity system based on a quarter each of renewables, nuclear, coal-fired and gas-fired combined-cycle stations, the conversion factor would be slightly above 2. When taking transmission & distribution losses into account, the factor should be 4-10% higher. [Targosz, 2005]

For electricity systems where additional electricity demand is supplied by renewables or combined cycle power stations, the primary energy factors would be respectively 1.07 and 1.8.

4 High efficiency applications

4.1 Replacing electricity with less electricity

The efficiency of appliances to convert electricity into energy services is increasing steadily, and still has improvement potential. For example:

- Losses in refrigeration have been reduced historically by a factor 5 [Norgard, 2001], from the levels at the end of the 80's to the best available technology in class A+ appliances (fig 3).

- Energy use for individual lighting applications can be reduced by a factor 5 or more (fig 4). Modern lighting solutions are 50-100 times more efficient than candles.
- Distribution transformers, one of the most efficient machines ever designed by man, can still reduce losses by a factor 3-4 through the use of amorphous iron
- In motor driven systems (pumps, compressors, fans, washing machines, electric trains), it is possible to reduce losses by 30% on average.

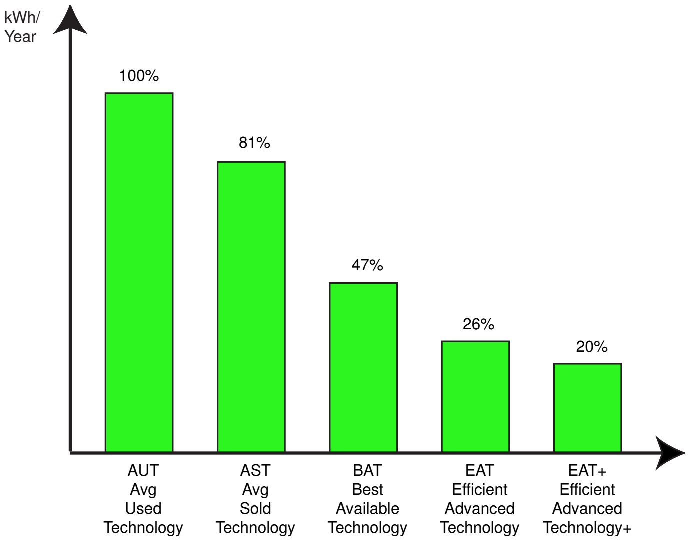

Figure 3: Various levels of end-use efficiencies [Norgard, 2001]

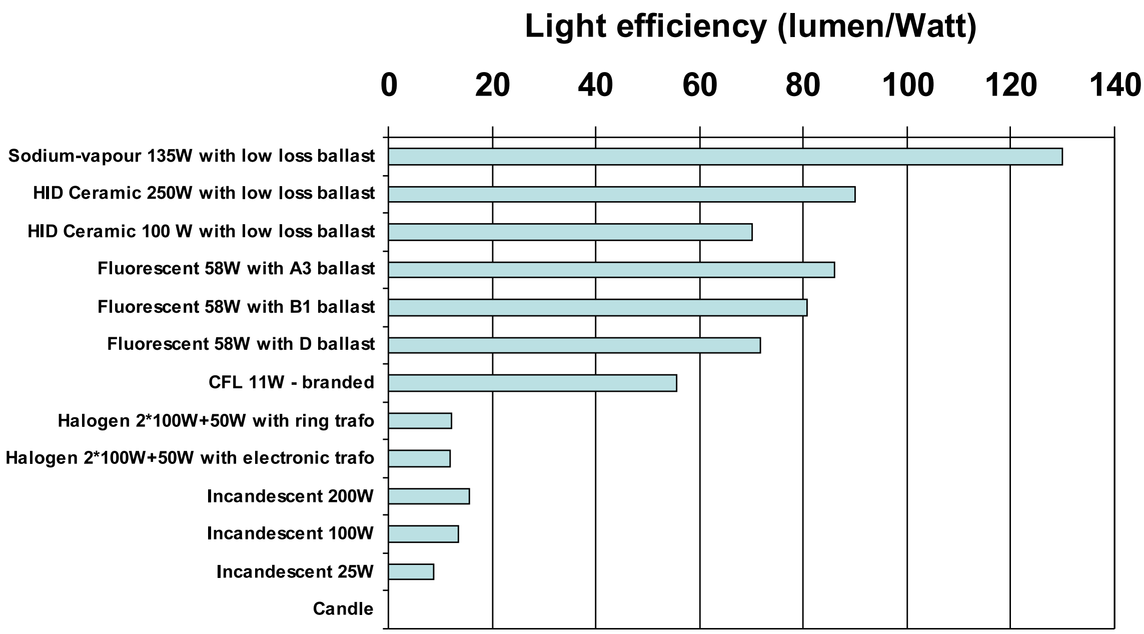

Figure 4: Efficiency of individual lighting solutions can vary a factor 10 [European Ballast Group]

But above examples just provide a static perspective, whereas electrotechnologies sometimes have more dramatic impacts at the systems level.

4.2 Using electricity instead of other energy carriers to save primary energy and CO_2 emissions

Because of its high quality, using electricity instead other energy carriers can have a boosting effect to save primary energy and reduce greenhouse gas emissions, even when including conversion losses in power generation:

- The use of high speed electric trains instead of air transport reduces primary energy use per passenger.km by a factor 3 and CO_2 emissions by a factor 4 [Eurelectric, 2004].
- Using electric trains instead of diesel trains reduces CO_2 emissions by a factor 4 and primary energy use by a factor 2 [Eurelectric, 2004].
- Electric vehicles are twice as efficient as vehicles with internal combustion engines (table 1).
- Efficient heat pumps, drawing heat from the underground require 20-40 kWh of electricity to supply 100 kWh of heat; they typically reduce final energy demand for heating by at least a factor 3 and primary energy demand by at least 25%.
- With induction heaters for cooking, 90% of (final) energy goes in the pan, compared to 55% for gas-fired cooking.
- Modern high temperature heating solutions for industrial processes can in some cases save up to 80% of primary energy and up to 60% of CO_2 emissions through their efficient use of primary energy (table 2).

	Gas-fired melting furnace	Induction oven
Combustion loss	1-5%	0.3-1%
Final energy	310 - 1550 kWh/t	93 - 310 kWh/t
Primary energy	1700 - 8500 MJ/t	510 - 1700 MJ/t
CO_2 emissions	91 - 455 kg/t	27 - 91 kg/t

Table 2: Comparison of characteristics for gas-fired melting furnace and induction oven for Aluminium [Böhmer, 2001]

4.3 Electricity for an efficient economy

At the next level, electricity – the only energy carrier that can power the digital economy – enables system-level efficiencies, eliminating or drastically reducing the need for certain energy services:

- Teleworking, reducing the need to commute
- Videoconferencing or webconferencing, reducing the need for travel
- Heating controls for building energy management, ensuring buildings are only heated when needed
- Dimmable lighting systems, ensuring exactly the right amount of light in the right place at the right time
- Process control technologies, especially in industry

5 Conclusion

With the increasing conversion efficiency of electricity in generation, the increasing share of renewable electricity, the high efficiency at the point of use and the potential for system level efficiencies, there is a lot of supporting evidence for a claim that electricity can save energy.

Considering the high quality of electricity, its inefficient use and high stand-by losses are a waste that needs to be avoided, without impairing its potential benefits to reduce primary energy and reduce greenhouse gas emissions in many other areas.

Contacts

For information or comments, contact the authors, or one of the contacts below:

- **Int'l:** Hans De Keulenaer
- **Belgium:** Benoit Dome
- **Italy:** Angelo Baggini
- **Poland:** Roman Targosz
- **UK:** David Chapman

Email contacts:

`<first name>.<last name>@sealnet.org.`

References

[Böhmer, 2001] Till Böhmer et al, Energiesparen mit Strom, Olzog, 2001

[CEER, 2005] Council of European Energy Regulators, 3rd Benchmarking Report on Quality of Electricity Supply, 2005

[EPRI, 2003] EPRI, Electricity Technology Roadmap, 2003, available from www.epri.com/corporate/discover_epri/roadmap/index.html

[Eurelectric, 2004] Eurelectric and UIE, Electricity for More Efficiency: Electric Technologies and their Energy Savings Potential, July 2004

[European Ballast Group] Discussions with lighting experts

[Evans, 2004] Marie-Ann Evans, New Electro-technologies: Energy Efficiency, XV UIE International Conference (Plugging into the world - Thinking Global Acting Local)

[Factor Four, 1997] Ernst Ulrich von Weizscker, Amory und Hunter Lovins, Factor Four Doubling Wealth, Halving Resource Use, Earthscan, 1997

[Grawe 2002] Joachim Grawe, Kann man mit Strom Energie sparen?, Energie-Fakten, May 2002, available from www.energie-fakten.de

[Husain] Iqbal Husain, Electric and Hybrid Vehicles - Design Fundamentals, CRC Press

[IEA] For an explanation of the physical energy content method: www.iea.org/Textbase/stats/questionnaire/faq.asp#Q1

[IEA02] International Energy Agency, World Energy Outlook 2002

[LPQI01] David Chapman, Introduction to Power Quality, Power Quality Application Guide, November 2001, www.lpqi.org

[Norgard, 2001] J S Norgard, Sustainable Energy Future - Nordic Perspective, Pan-European NGO Sustainable Energy Seminar, September 2001

[Targosz, 2005] Roman Targosz (editor), Global energy savings potential from high efficiency distribution transformers, Leonardo ENERGY, February 2005, available from www.leonardo-energy.org

[Voorspools, 2000] , Kris R. Voorspools and William D. D'haeseleer, The influence of the instantaneous fuel mix for electricity generation on the corresponding emissions, Energy, Vol 25 No 11, Pages 1119-1138

[WBCSD, 2000] World Business Council for Sustainable Development, Exploring Sustainable Development, 2000

[WEA, 2000] UNDP, World Energy Assessement, 2000